CLAIMS

1. Communications apparatus, comprising:

a transmitter, which comprises:

a Tomlinson-Harashima precoder, which is coupled to receive and precode a sequence of input symbols, so as to generate a corresponding sequence of precoded symbols; and

transmit circuitry, which is adapted to process the precoded symbols so as to generate a signal for transmission over a communication channel; and

a receiver, which is coupled to receive the signal over the channel, and which comprises:

a feed-forward equalizer (FFE), adapted to apply a feed-forward equalization function to the signal, so as to generate a sequence of equalized samples;

a decision block, which is coupled to receive the equalized samples from the FFE and to generate a sequence of decision output samples responsive thereto, the decision block comprising an adaptive filter, having coefficients determined adaptively responsive to a characteristic of the channel, an indication of which coefficients is conveyed by the receiver to the transmitter for implementation in the precoder; and

a Tomlinson-Harashima decoder, which is coupled to receive a sequence of input samples comprising at least one of the sequence of decision output samples generated by the decision block and the sequence of equalized samples generated by the FFE, and to

decode the input samples in order to reconstruct the sequence of input symbols.

2. Apparatus according to claim 1, wherein the equalized samples do not undergo Tomlinson-Harashima decoding before they are received by the decision block.

3. Apparatus according to claim 1, wherein the Tomlinson-Harashima precoder is adapted to precode the input symbols such that the precoded symbols are within a predetermined modulo range, and wherein the decision block comprises an extended slicer, which is adapted to generate the decision output samples over an extended range that is greater than the modulo range.

4. Apparatus according to claim 1, wherein the adaptive filter comprises a decision feedback equalizer.

5. Apparatus according to claim 1, wherein the adaptive filter comprises an adaptive error predictor.

6. Apparatus according to claim 1, wherein the Tomlinson-Harashima decoder is coupled to receive the sequence of equalized samples generated by the FFE, and wherein the receiver further comprises a decision device, which is coupled to receive the decoded input samples from the decoder and to generate the reconstructed input symbols.

7. Apparatus according to claim 1, wherein the receiver is adapted to compute a cost function, indicative of a change in the coefficients of the adaptive filter, and to convey the indication of the coefficients to the transmitter when the cost function exceeds a predetermined threshold.

8. Apparatus according to claim 1, wherein the Tomlinson-Harashima precoder comprises a feedback loop filter having a filter response DFET(z), and wherein the adaptive filter comprises a decision feedback equalizer having an equalizer response DFE(z) and an error predictor having an error prediction response EP(z), and wherein after the indication of the coefficients is conveyed to the transmitter, an updated filter response DFET'(z) is implemented in the feedback loop filter substantially as given by DFET'(z) = [1+DFET(z)][1+DFE(z){1-EP(z)}-EP(z)]-1.

9. Apparatus according to claim 8, wherein after the updated filter response is implemented in the feedback loop filter, the equalizer response DFE(z) and the error prediction response EP(z) are set to zero.

10. Apparatus according to claim 9, wherein the FFE has an adaptively-determined feed-forward response FFE(z), and wherein the error predictor comprises a finite impulse response filter have a number of taps N, and wherein when the indication of the coefficients is conveyed to the transmitter for implementation in the precoder, an updated feed-forward response FFE'(z) is implemented in the FFE substantially as given by FFE'(z) = FFE(z)(1-EP(z^N)).

11. Apparatus according to claim 8, wherein the feedback loop filter comprises a finite impulse response filter having a predetermined number of taps, and wherein a time-domain representation of the updated filter response DFET'(z) is adjusted so as to implement the updated filter response using the predetermined number of taps.

12. Apparatus according to claim 1, wherein the Tomlinson-Harashima precoder comprises a feedback loop filter having a filter response DFET(z), and wherein the adaptive filter comprises a decision feedback equalizer having an equalizer response DFE(z), and wherein after the indication of the coefficients is conveyed to the transmitter, an updated filter response DFET'(z) is implemented in the feedback loop filter substantially as given by DFET'(z) = [1+DFET(z)][1+DFE(z)]-1.

13. Apparatus according to claim 1, wherein the Tomlinson-Harashima precoder comprises a feedback loop filter having a filter response DFET(z), and wherein the adaptive filter comprises an error predictor having an error prediction response EP(z), and wherein after the indication of the coefficients is conveyed to the transmitter, an updated filter response DFET'(z) is implemented in the feedback loop filter substantially as given by DFET'(z) = [1+DFET(z)][1-EP(z)]-1.

14. Apparatus according to claim 1, wherein the Tomlinson-Harashima precoder comprises a feedback loop filter, and wherein the indication of the coefficients conveyed by the receiver to the transmitter comprises values of the coefficients, based upon which a filter response of the feedback loop filter is calculated and implemented at the transmitter.

15. Apparatus according to claim 1, wherein the Tomlinson-Harashima precoder comprises a feedback loop filter, and wherein a filter response of the feedback loop filter is calculated at the receiver based on the coefficients, such that the indication of the

coefficients conveyed by the receiver to the transmitter comprises the calculated filter response.

16. A receiver, for receiving a signal transmitted over a channel by a transmitter that includes a Tomlinson-Harashima precoder, the receiver comprising:

a feed-forward equalizer (FFE), adapted to apply a feed-forward equalization function to the signal, so as to generate a sequence of equalized samples;

a decision block, which is coupled to receive the equalized samples from the FFE and to generate a sequence of decision output samples responsive thereto, the decision block comprising an adaptive filter, having coefficients determined adaptively responsive to a characteristic of the channel; and

a Tomlinson-Harashima decoder, which is coupled to receive and decode the decision output samples so as to reconstruct the sequence of input symbols.

17. A receiver according to claim 16, wherein the equalized samples do not undergo Tomlinson-Harashima decoding before they are received by the decision block.

18. A receiver according to claim 16, wherein the Tomlinson-Harashima decoder has a predetermined modulo range, and wherein the decision block comprises an extended slicer, which is adapted to generate the decision output samples over an extended range that is greater than the modulo range.

19. A receiver according to claim 16, wherein the adaptive filter comprises a decision feedback equalizer.

20. A receiver according to claim 16, wherein the adaptive filter comprises an adaptive error predictor.

21. A receiver, for receiving a signal transmitted over a channel by a transmitter that includes a Tomlinson-Harashima precoder for precoding input symbols to be conveyed in the transmitted signal, the receiver comprising:

a feed-forward equalizer (FFE), adapted to apply a feed-forward equalization function to the signal, so as to generate a sequence of equalized samples;

a decision block, which is coupled to receive the equalized samples from the FFE and to generate a sequence of decision output samples responsive thereto, the decision block comprising an adaptive filter, having coefficients determined adaptively responsive to a characteristic of the channel, an indication of which coefficients is conveyed by the receiver to the transmitter for implementation in the precoder;

a Tomlinson-Harashima decoder, which is coupled to receive and decode the equalized samples from the FFE; and

a decision device, which is coupled to receive and process the decoded samples from the decoder so as to reconstruct the input symbols.

22. A receiver according to claim 21, wherein the equalized samples do not undergo Tomlinson-Harashima decoding before they are received by the decision block.

23. A receiver according to claim 21, wherein the Tomlinson-Harashima decoder has a predetermined modulo range, and wherein the decision block comprises an extended slicer, which is adapted to generate the decision output samples over an extended range that is greater than the modulo range.

24. A receiver according to claim 21, wherein the adaptive filter comprises a decision feedback equalizer.

25. A receiver according to claim 21, wherein the adaptive filter comprises an adaptive error predictor.

26. A receiver according to claim 21, wherein the indication of the coefficients conveyed by the receiver to the transmitter comprises values of the coefficients, for calculation of a filter response of a feedback loop filter in the Tomlinson-Harashima precoder based on the values.

27. A receiver according to claim 21, wherein a filter response of a feedback loop filter in the Tomlinson-Harashima precoder is calculated at the receiver based on the coefficients, such that the indication of the coefficients conveyed by the receiver to the transmitter comprises the calculated filter response.

28. A method for conveying data over a communication channel, comprising:

precoding a sequence of input symbols at a transmitter using a Tomlinson-Harashima precoder having a predetermined modulo range;

transmitting the precoded symbols as a signal over the communication channel from the transmitter to a receiver;

receiving and processing the signal at the receiver to generate a sequence of received samples;

determining a sequence of decision output values of the received samples over a range of values greater than the modulo range of the precoder;

processing the decision output values using an adaptive filter so as to determine filter coefficient values responsive to a characteristic of the channel;

conveying an indication of the coefficient values to the transmitter for implementation in the precoder; and

decoding a sequence of input samples using a Tomlinson-Harashima decoder at the receiver so as to reconstruct the sequence of input symbols, the sequence of input samples comprising at least one of the sequence of received samples and the sequence of decision output values.

29. A method according to claim 28, wherein conveying the indication comprises conveying the values of the coefficients, for calculation of a filter response of a feedback loop filter in the Tomlinson-Harashima precoder based on the values.

30. A method according to claim 28, wherein conveying the indication comprises calculating a filter response of a feedback loop filter in the Tomlinson-Harashima precoder at the receiver based on the coefficient values, and conveying the calculated filter response to the transmitter.

31. A method according to claim 28, wherein determining the sequence of decision output values comprises processing the received samples without prior Tomlinson-Harashima decoding of the received samples.

32. A method according to claim 28, wherein processing the decision output values comprises applying decision feedback equalization to the received samples using the values, so that the filter coefficients comprise adaptive decision feedback equalization coefficients.

33. A method according to claim 28, wherein processing the decision output values comprises applying error prediction to the received samples using the values, so that the filter coefficients comprise adaptive error prediction coefficients.

34. A method according to claim 28, wherein decoding the sequence of input samples comprises applying a modulo operation to the sequence of received samples so as to generate decoded samples within the predetermined modulo range, and applying a decision device to the decoded samples so as to reconstruct the input symbols.

35. A method according to claim 28, wherein conveying the indication of the coefficient values to the transmitter comprises computing a cost function, indicative of a change in the coefficient values, and conveying the indication of the coefficients to the transmitter when the cost function exceeds a predetermined threshold.

36. A method according to claim 28, wherein determining the filter coefficient values comprises determining a decision feedback equalization response DFE(z) and an error prediction response EP(z), and wherein precoding the sequence of input symbols comprises precoding the symbols using a feedback loop filter having a filter response DFET(z), and recalculating DFET(z) after the indication of the coefficients is conveyed to the transmitter to generate an updated filter response DFET'(z) substantially as given by $DFET'(z) = [1+DFET(z)][1+DFE(z)\{1-EP(z)\}-EP(z)]-1$.

37. A method according to claim 36, wherein processing the decision output values comprises, after the updated

filter response is implemented in the feedback loop filter, setting the equalization response DFE(z) and the error prediction response EP(z) to zero.

38. A method according to claim 37, wherein processing the decision output values comprises applying the error prediction response EP(z) using a finite impulse response filter have a number of taps N, and wherein receiving and processing the signal at the receiver comprises applying feed-forward equalization to the signal with an adaptively-determined feed-forward response FFE(z), and when the error prediction response is set to zero, adjusting the feed-forward response to an updated response FFE'(z) substantially as given by $FFE'(z) = FFE(z)(1-EP(z^N))$.

39. A method according to claim 36, wherein using the feedback loop filter comprises applying a finite impulse response filter having a predetermined number of taps, and wherein recalculating DFET(z) comprises adjusting a time-domain representation of the updated filter response DFET'(z) so as to implement the updated filter response using the predetermined number of taps.

40. A method according to claim 39, wherein adjusting the time-domain representation comprises truncating the representation.

41. A method according to claim 28, wherein determining the filter coefficient values comprises determining a decision feedback equalization response DFE(z), and wherein precoding the sequence of input symbols comprises precoding the symbols using a feedback loop filter having a filter response DFET(z), and recalculating DFET(z) after the indication of the coefficients is conveyed to

the transmitter to generate an updated filter response DFET'(z) substantially as given by DFET'(z) = [1+DFET(z)][1+DFE(z)]-1.

42. A method according to claim 28, wherein determining the filter coefficient values comprises determining an error prediction response EP(z), and wherein precoding the sequence of input symbols comprises precoding the symbols using a feedback loop filter having a filter response DFET(z), and recalculating DFET(z) after the indication of the coefficients is conveyed to the transmitter to generate an updated filter response DFET'(z) substantially as given by DFET'(z) = [1+DFET(z)][1-EP(z)]-1.

43. A method for conveying data over a communication channel, comprising:

precoding a sequence of input symbols at a transmitter using a Tomlinson-Harashima precoder and a feedback loop filter having a filter response DFET(z);

transmitting the precoded symbols as a signal over the communication channel from the transmitter to a receiver;

applying feed-forward equalization to the signal at the receiver, with an adaptive feed-forward equalization response FFE(z), to generate a sequence of equalized samples;

processing the equalized samples using an adaptive feedback filter so as to determine feedback filter coefficient values responsive to a characteristic of the channel;

conveying an indication of the feedback filter coefficient values to the transmitter for implementation in the feedback loop filter of the precoder;

updating the values of DFET(z) and FFE(z) responsive to the feedback filter coefficient values; and

decoding the equalized samples using a Tomlinson-Harashima decoder at the receiver so as to reconstruct the sequence of input symbols.

44. A method according to claim 43, wherein conveying the indication comprises conveying the values of the coefficients, and wherein updating the value of DFET(z) comprises calculating an updated value of DFET(z) at the transmitter based on the values of the coefficients.

45. A method according to claim 43, wherein conveying the indication comprises calculating an updated value of DFET(z) at the receiver based on the coefficient values, and conveying the calculated value to the transmitter.

46. A method according to claim 43, wherein processing the equalized samples comprises processing the equalized samples without prior Tomlinson-Harashima decoding of the equalized samples.

47. A method according to claim 46, wherein precoding the sequence of input symbols comprises applying a modulo operation to the input symbols with a predetermined modulo range, and wherein processing the equalized samples comprises determining a sequence of decision output values of the received samples over a range of values greater than the modulo range of the precoder, and determining the feedback filter coefficient values based on the decision output values.

48. A method according to claim 47, wherein decoding the equalized samples comprises applying the Tomlinson-Harashima decoder to the decision output values.

49. A method according to claim 46, wherein decoding the equalized samples comprises applying the Tomlinson-Harashima decoder to the equalized samples without first having processed the equalized samples using the adaptive feedback filter.

50. A method according to claim 43, wherein processing the equalized samples comprises applying error prediction to the samples, so that the filter coefficient values comprise values corresponding to an error prediction response $EP(z)$.

51. A method according to claim 50, wherein processing the equalized samples further comprises applying decision feedback equalization to the samples, so that the filter coefficient values comprise further values corresponding to a decision feedback equalization response $DFE(z)$.

52. A method according to claim 51, wherein updating the value of $DFET(z)$ comprises recalculating $DFET(z)$ to generate an updated filter response $DFET'(z)$ substantially as given by $DFET'(z) = [1+DFET(z)][1+DFE(z)\{1-EP(z)\}-EP(z)]-1$.

53. A method according to claim 50, wherein updating the value of $DFET(z)$ comprises recalculating $DFET(z)$ to generate an updated filter response $DFET'(z)$ substantially as given by $DFET'(z) = [1+DFET(z)][1-EP(z)]-1$.

54. A method according to claim 50, wherein processing the equalized samples comprises applying the error prediction response EP(z) using a finite impulse response filter have a number of taps N, and wherein updating the value of FFE(z) comprises recalculating FFE(z) to generate an updated response FFE'(z) substantially as given by $FFE'(z) = FFE(z)(1-EP(z^N))$.

55. A method according to claim 43, wherein processing the equalized samples comprises applying decision feedback equalization to the samples, so that the filter coefficient values comprise values corresponding to a decision feedback equalization response DFE(z), and wherein updating the value of DFET(z) comprises recalculating DFET(z) to generate an updated filter response DFET'(z) substantially as given by $DFET'(z) = [1+DFET(z)][1+DFE(z)]-1$.

56. A method according to claim 43, wherein processing the equalized samples comprises, after updating the value of DFET(z) and FFE(z), setting at least some of the feedback filter coefficient values to zero.

57. A method according to claim 43, wherein using the feedback loop filter comprises applying a finite impulse response filter having a predetermined number of taps, and wherein updating the value of DFET(z) comprises adjusting a time-domain representation of the updated value so as to implement the updated filter response using the predetermined number of taps.

58. A method according to claim 57, wherein adjusting the time-domain representation comprises truncating the representation.

59. A method according to claim 43, wherein updating the values of DFET(z) and FFE(z) comprises determining initial values of DFET(z) and FFE(z) during a start-up phase of the transmitter and the receiver, and altering the values at intervals thereafter during an operational phase of the transmitter and the receiver.

60. A method according to claim 59, wherein altering the values comprises computing a cost function, indicative of a change in the feedback filter coefficient values, and conveying the indication of the coefficients to the transmitter when the cost function exceeds a predetermined threshold.